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TRACER EXPERIMENTS IN EASTERN DEVONIAN SHALE

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ABSTRACT

For the purpose of characterizing the properties of the Eastern Devonian gas shale, a seven-day tracer experiment was carried out in August of 1981 by the Los Alamos National Laboratory as part of the DOE's Offset-Well Test. Two wells had been drilled in a Columbia Gas Company field in southeastern Ohio, each with a downhole separation of approximately 120 feet from an existing production well. The isoceles triangle formed by the three wells had an apex angle of approximately 110 degrees. About 56,000 SCF of nitrogen were injected into a producing zone located at a depth of 3300 feet in one of the wells. Gas was then produced from the various wells at different rates and pressures for the duration of the test. Both pressure and gas composition in the three wells were monitored thoughout the test.

INTRODUCTION

The efficient recovery of methane from many tight formations awaits the implementation of improved stimulation techniques. Determination of the appropriate method can be assisted by a better understanding of the methane storage and transport within the rock. It was to show how this better understanding can be attained that the Los Alamos National Laboratory carried out a seven-day tracer experiment in an eastern gas field as part of the Department of Energy's Offset Well Test.

The gas in the field tested is held in Devonian shale. Structurally, these shales consist of a low porosity matrix pierced throughout by a complex network of fractures generally vertical relative to the horizontal bedding planes. Although methane gas has been produced from Devonian shales in the Appalachian Basin for more than fifty years, there is still a wide range of opinion concerning the nature of the underground storage of the gas. Stimulation methods for production wells vary, depending on whether the methane is stored in the pores or in the fractures. One of the purposes of the tracer test was to determine the relative amounts of gas in the different storage media.

The test was based on a concept[1] originally proposed by Lincoln F. Elkins of Sohio Oil Company. It used an old methane well, which continues to be a useful production well even after eighteen years of flow. In addition, the experiment employed two new wells drilled near the production well as part of the DOE's Offset Well Test. In Elkins's concept, a tracer or tracers would be injected into one of the wells, and then this well back-produced. The concentration-time behavior of the tracers in the well effluent would give information concerning the storage characteristics of the gas in the shale.

In our test, we injected 56,000 SCF of nitrogen into one of the new wells and subsequently back-produced this injection well. The old production well and the second new well were allowed to flow at rates sufficient for chemical analysis. Rates were sometimes higher than this, due to leaks, but the essential flow rates for all times could be calculated. Species-concentration and pressure data were collected at all three wells throughout the test.

BACKGROUND TO EXPERIMENT

Geology

Broad intercontinental seas deposited the sediments that make up the middle and Upper Devonian shales of Ohio. Descending from the surface, the Devonian shale layers that occur in southeastern Ohio are the Cleveland Member, the Chargin Member, and the Huron Member.[2] The Huron Member is dark-gray to black in color and is the most highly organic of the Ohio Shales. The gas-producing zones are found in this latter member. The Huron shale is composed primarily of silt, clay, and carbonaceous matter. The layer contains a network of interconnected vertical

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References and illustrations at end of paper.

Work performed under the auspices of the US DOE, Morgantown Energy Technology Center. K.-H. Frohne, Technical Project Officer.

fractures. For the Huron Member in Meigs County, where the test was performed, the highest frequency of parallel fractures has a N50°E to N60°E trend.[3]

Configuration

Two wells were drilled near a producing methane well, which is officially registered as Well 10056. Well 10056 is referred to as Well C in the remainder of this report. Well A was offset from Well C in a direction parallel to the primary fracture trend described above. Well B was offset from Well C in a direction approximately perpendicular to the trend. Figure 1 shows the orientation and downhole separation of the three wells. The angle ACB is about 110° and the distances AC and CB are 118 ft.

Each well was drilled to a total depth of about 3500 ft, which is near the base of the Huron Member. The major gas producing zone lies in the interval 85-115 ft above the 3400 ft level in Wells A and C. From pressure build-up tests[4], we conclude that Well B is not in close communication with Wells A and C.

Figure 2 summarizes the hole configuration in each well. Well C has a total depth of 3400 ft. The well is cased to a depth of 2120 ft and has a diameter of 7 inches. Below this level the hole is uncased, having a nominal 6 1/4 in. diameter. The lower 200 ft of the well was shot loaded with nitroglycerin to enhance communication with the natural fracture network. Steel tubing having an inside diameter of 2.05 in. was inserted from the surface to a depth of 3400 ft. The lower 100 ft of the tubing is slotted to allow gas flow into the string. Figure 2b shows an enlarged view of the lower 170 ft of well C. A downhole pressure package and supporting wire cable are also shown.

Wells A and B have 8 in. diameters and are cased to a depth of 2100 ft. The total depth of Well A is 3484 ft; of Well B, 3478 ft. A packer was set in Well A at a depth of 3315 ft, and tubing with a diameter of 2.05 in. was inserted from the surface through the center of the packer. No central tubing string was inserted into Well B. Figures 2c and 2d show downhole pipe configurations for Wells A and B, respectively.

Instrumentation

The experiment consisted of two principal phases; an injection phase and a back-production phase, both implemented at Well A. Pressure and concentration time histories were measured at various locations throughout the test. The initial and boundary conditions were carefully selected and monitored so that the introduction of possible ambiguities in the data could be minimized. It was felt that the unambiguous interpretation of the results required a continuous injection phase. That is, if injection were interrupted for some reason or another, we would proceed immediately to back production, phase 2. Logistical arrangements permitted the uninterrupted injection of N_2 for 9-3/4 hrs at a constant wellhead pressure of 650 psi.

This pressure was selected for three reasons. First, it lies well below the virgin reservoir pressure before drilling (800 psi) and would therefore be unlikely to alter the existing fracture network. Second, it lies sufficiently above the shut-in pressure (400 psi) of the reservoir to force the tracer gas into the pore space, if such a storage potential exists. Third, it lies safely below the maximum pressure-differential constraints of the packer, set in Well A to isolate the major gas-producing zone. Based on pressure and temperature data and on the respective N_2 tube trailer volumes, the total amount of N_2 injected was calculated to be 56,000 SCF.

At the start of phase 2, Well A was back-produced through a pressure regulator. When the pressure at the wellhead had dropped to 100 psi, the regulator was adjusted to maintain this pressure for the remainder of the test. A small amount of gas (80 SCFH) was drawn off and run through the sampling lines of the Los Alamos instrument trailer. The experimental plan called for the flow at Wells C and B to be restricted to 80 SCFH; however, this boundary condition was not fulfilled because of a slow leak around a coupling near the base of the Well B christmas tree and because of a profusely and sporadically leaking rubber seal at Well C. A compressed N_2-driven greaser was on location at Well C to prevent the leak, but the grease seal was breached several times during the test. From the data behavior, the flow rates from Well C during the leak periods can be calculated with reasonable accuracy. The leak at Well B was constant and while not quantifiable from measured data, it offers no real hindrance to our final interpretations because of the relatively low level of reservoir interaction at B. These matters are discussed in the data-summary section below.

The computer-controlled, data-collection system was housed in a Los Alamos instrument trailer. The 32-ft standard trailer was blocked and cribbed at a location midway between Wells A and B. An HP-9835 computer activated the gas sampling system and recorded pressures. The system extracted gas samples from each wellhead in staggered sequence or in any order requested by the operator. The minimum time required for a particular sample to be analyzed by the gas chromatograph was twenty minutes; so if all three wells were being analyzed, each well was sampled once every hour. Alternatively, a given well could be sampled three times every hour if the operator so desired. The HP-583A gas chromatograph analyzed the production gases and recorded the data on a floppy disc. A hard copy of the data was also made on a data logger.

The trailer was connected to the wells with half-inch copper tubing, using the existing fittings at the wellheads. Relief valves outside the trailer protected its system from the back-flow of high pressure gas from the wells. All tubing inside the trailer was stainless steel. In addition to the gas sample taken, six independent pressure measurements were recorded by the HP-9835 every twenty minutes. One pressure transducer was located in each of the wellheads and one in the annulus of Well A for the duration of the test. The fifth transducer was used in the tube trailer injection line during phase 1. The sixth transducer was used part of the time in the back-flow line of Well A as a safety feature, providing a means for identifying excessive pressure build-up.

The Morgantown Energy Technology Center recorded downhole pressures in Wells A and B, using two Amerada RPG-3 gauges for continuous pressure scribing. The gauge placed in well B had a 180-hr clock and a peak pressure range of 1000 psig. The gauge used in Well A had a 144-hr clock and a maximum pressure range of 1500 psig. The gauges were pulled from the holes midway through the test, so the clocks could be rewound, and were then reinserted. These pressure measurements were used as a check on the wellhead pressures we recorded.

EXPERIMENTAL RESULTS

Pressure data

The wellhead pressures for the three wells throughout the test are presented in Fig. 3. As mentioned earlier, downhole pressures were recorded by Morgantown Energy Technology Center, and these were consistent with the pressures given in Fig. 3.

The injection period is clearly visible in the Well A pressures, followed by a very fast pressure drop to the range of 100 psi. It remained there throughout the rest of the experiment. Minor fluctuations in the pressure occurred during this latter period, and the pressure was controlled manually by modifying the flow rate from the well.

The pressure in Well C (the old production well) rose steadily as nitrogen was injected, then proceeded to fall as the injection well was back-produced. Significant fluctuations in Well C's pressure occurred sporadically, indicating the occurrence of the leak described earlier. The slow pressure rises indicate the re-sealing of the well and the temporary elimination of the leak.

Well B's pressure trace merely shows a steady, though rather minor, rise throughout the duration of the experiment. The minor nature of this pressure rise indicates the lack of any sort of direct connection between Wells A and C and Well B.

Nitrogen composition data

The percentages of the nitrogen tracer in the three gases at the wellheads are presented in Fig. 4. It can be readily observed that there is marked structure in the data, and this augurs well for significant analysis.

FUTURE WORK

The stage is now set for analysis of the data. Computer codes have been developed for analyzing data of this type, based on carefully formulated mathematical models. The detailed interpretation requires matching the results from these models to the data presented above. The rock is characterized by two basically different forms of porosity and permeability. One of these describes the potentially anisotropic and non-homogeneous network of fractures that interlaces about the unfractured blocks. The other describes the properties of the blocks themselves.

The fundamental structure of our models is based on the principles of mass, momentum and energy transport of tracer-laden compressible gas through a porous and permeable material. For each new investigation a small number of parameters must be specified to characterize the rock. In part these can be measured by an analysis of samples from cores or outcrops. In part they must be derived by a careful comparison of calculational results with field-test data. When the data and calculational results closely match, then the parameters required for the matching calculations can be considered to characterize the rock properties. Moreover, the results of the matching calculation will yield an abundance of information that is unavailable from field measurements.

ACKNOWLEDGMENTS

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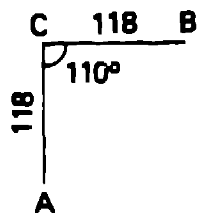
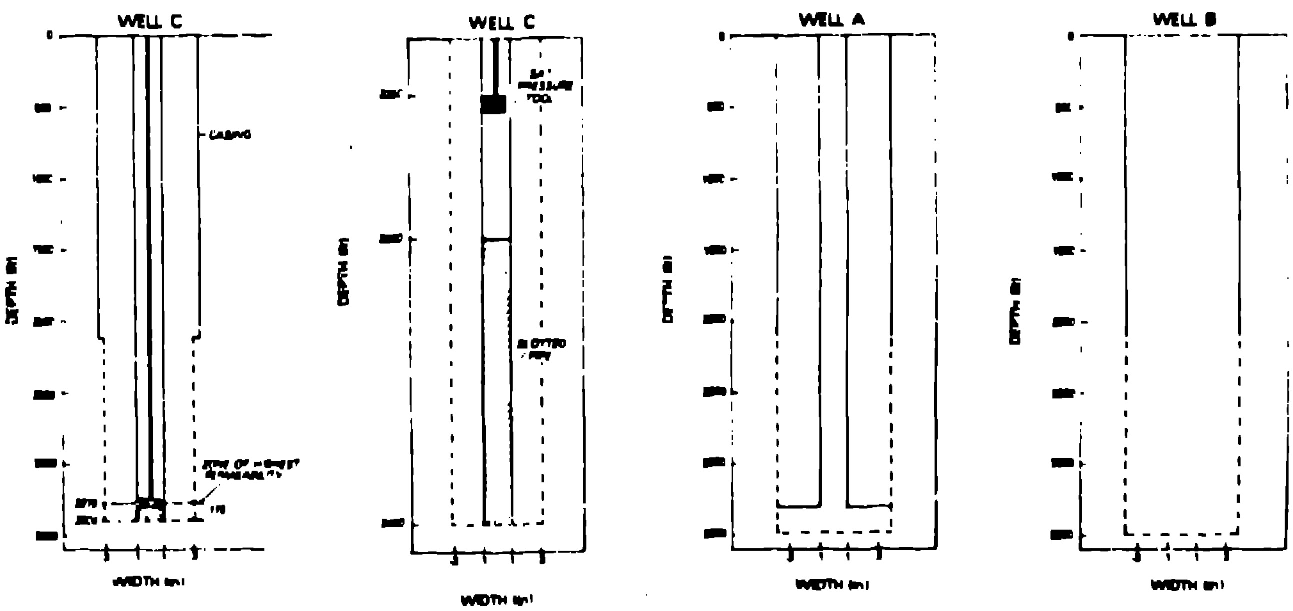


Downhole Well Separation
Figure 1



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Downhole Pipe Configuration
Figure 2

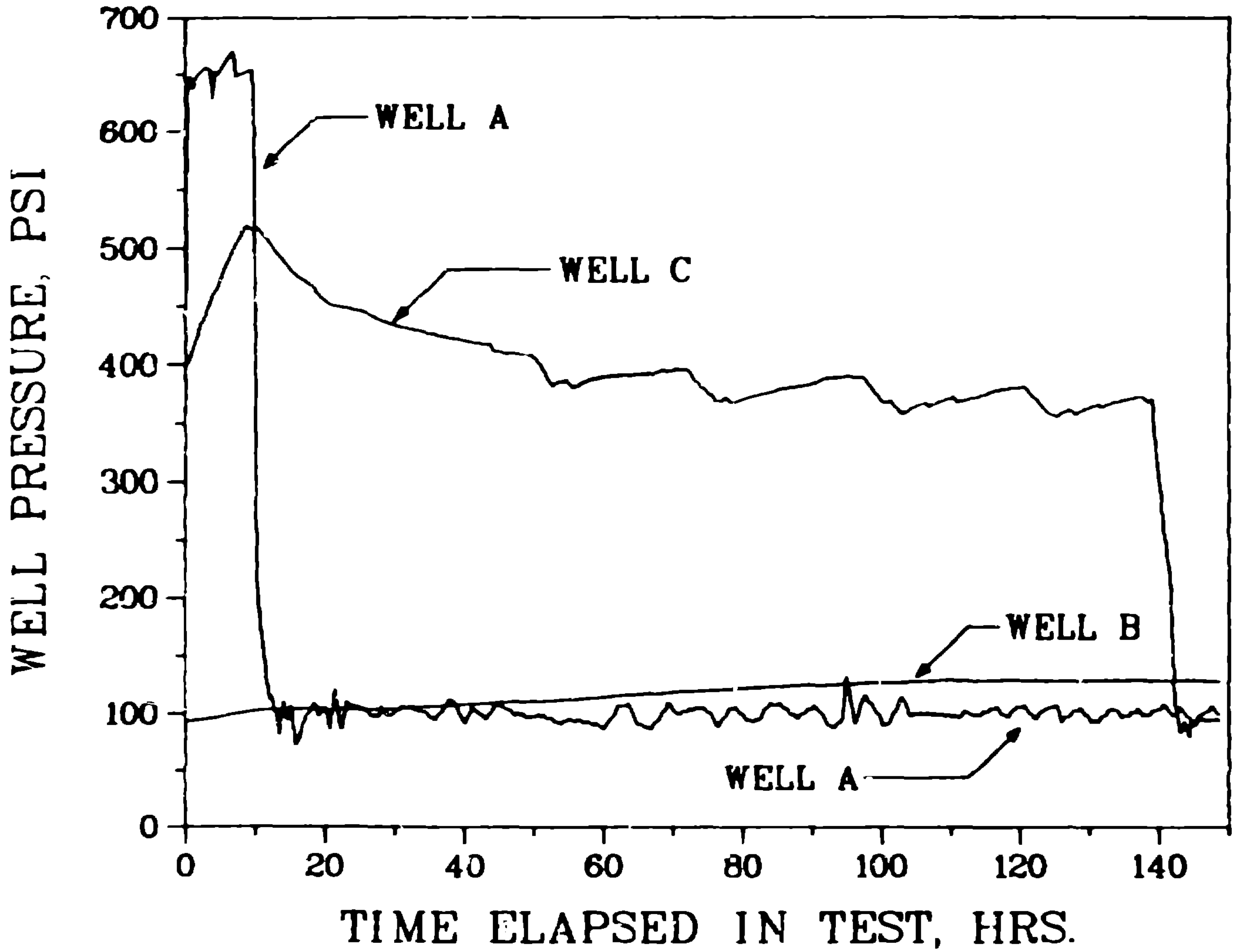

FIGURE 3. Wellhead Pressures

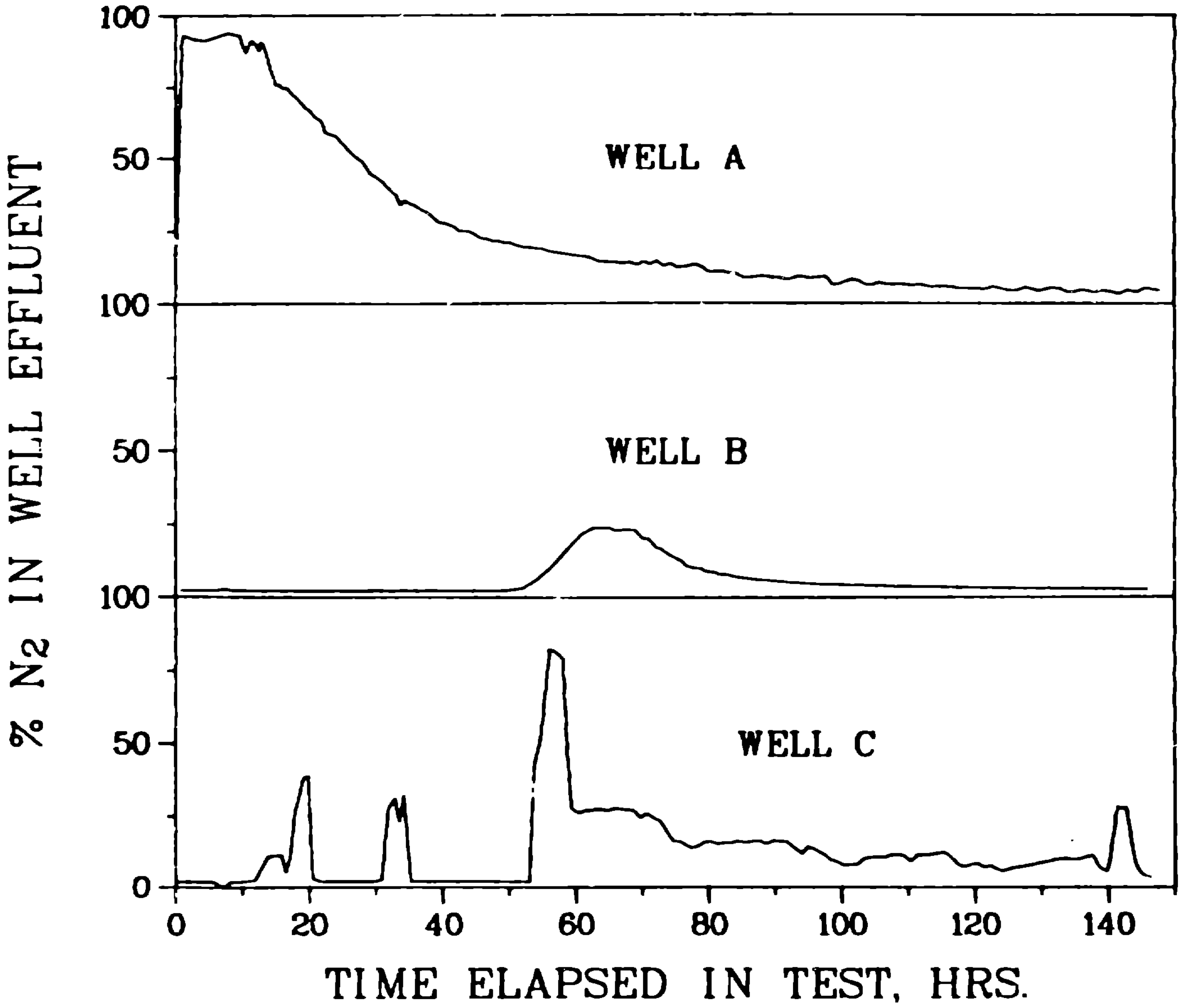

FIGURE 4. Tracer Concentration